DUAL PORT INDUCTION SYSTEM FOR DMB 1.4 MPI ENGINE

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Summary: *The paper presents the research results of DMB 1.4 l spark ignition engine equipped with prototype variable induction system. This variable geometry induction system was developed in order to investigate the possibilities of improving induction generated swirl and turbulence in combustion chamber and in this way to accelerate combustion, especially at low load engine condition. Induction channel in engine head was separated longitudinally into two sections using thin tin longitudinal wall and deflector valve at channel entrance was used to direct air flow into half channel cross section (at low engine load) or to enable full channel cross section (at full load). The results of combustion analysis show that combustion is accelerated and cycle variations are reduced at certain working conditions. In addition, specific fuel consumption is reduced, but very small, smaller than it was expected. Further geometry optimization and appropriate process managing is required.*
Key words: *Spark ignition engine, variable induction geometry, cylinder pressure recording , combustion analysis.*

1 INTRODUCTION

During engine induction system design, researchers have always been faced with the problem of optimal flow characteristics realization at engine different seeds and loads. Induction system optimal geometry can not be the same for all engine operating conditions. For example, inlet channels optimal length, enabling the utilization of pressure waves for "resonant filling" is longer for low engine speed and shorter for maximal speed. Therefore, either the compromise channel length must be accepted or a solution enabling variable pipe length should be applied, what significantly increase the engine cost. However, this problem, although very important is not topic of this paper.

Another problem, also very important, is the realization of optimal flow (air flow velocity, swirl and turbulence) in inlet channels and combustion chamber, what has crucial influence on mixture formation and homogenization and flame propagation through combustion chamber, i.e. heat release rate. At engine partial load and low

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engine speeds, small channel flow area is favorable in order to unable sufficient flow velocity. But such reduction of channel cross section is unfavorable at engine high load conditions since it has negative influence of volumetric efficiency. This problem can be successfully solved in the case of four valve engines, i.e. engines with two inlet valves and two separate inlet channel per cylinder, where a secondary channel can be throttled at low engine load (example Opel “twin port” system [1]). However, in the case of two valve engines, i.e. one inlet valve per cylinder, the problem is more complex for construction, and there are no similar solutions in engine commercial production. The aim of this work is the investigation of possibilities to realize the variability of inlet cross section in the case of two valve engine and to study the benefits of such solution.

An original idea is the principle shown in fig. 1. In order to accelerate inlet air flow in the entrance to the cylinder at engine low loads, it is necessary to reduce its cross section at least in final part of the channel. Also, air flow tangential entry into cylinder is favorable to enable swirl motion in combustion chamber. This can be achieved by separation of inlet channel in engine head in two sections using longitudinal tin wall and deflector plate located at the entrance of cylinder head. Such design enables practically two inlet channels, so one of them can be partially blocked and air flow directed to the other one. This is schematically shown in fig. 1, where longitudinal tin wall and deflector are shown only for first cylinder to simplifies the drawing and in practice other cylinders have the same system.

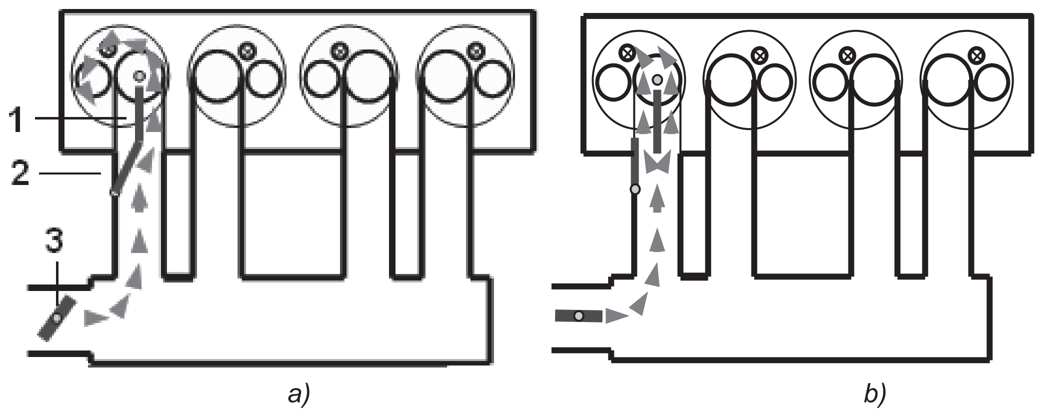


Fig. 1 *Schematic of “Dual port” variable induction system; a) low engine load; b) full engine load. (1 – tin wall, 2 – deflector, 3 – throttle valve)*

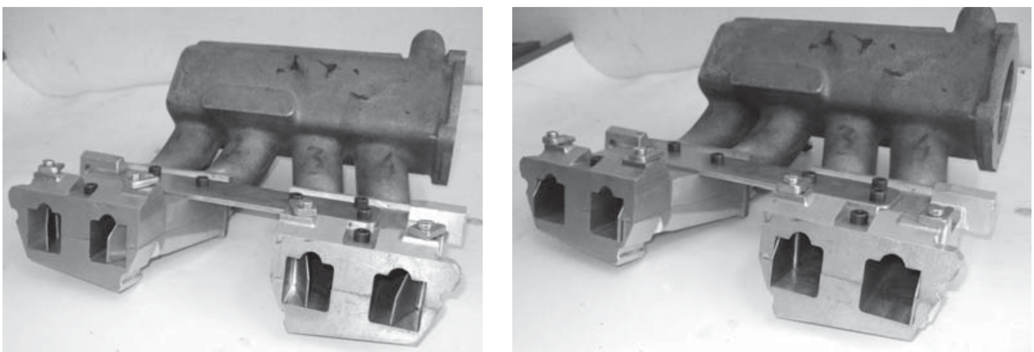
At engine partial loads and low speeds, the deflector closes one section of inlet port and the air flow is directed into another channel in which flow velocity is increased and the tangential entry into cylinder is achieved (fig. 1-a). At engine full load, when inlet air flow is high enough, it is necessary to enable low flow resistance in order to achieve high volumetric efficiency and consequently high power output. Then, deflectors are placed in the open position, so that both inlet channel in engine head are active and flow area is increased (fig. 1-b).

2 DESIGN OF „DUAL PORT“ VARIABLE INDUCTION SYSTEM

Laboratory prototype of variable induction system called “Dual port”, has been developed for spark ignition engine DMB 1.4 MPI, produced by engine factory “21 may Belgrade” [2]. It is four cylinder engine with swept volume of 1372 ccm and bore/ stroke ratio 80.5/67.4. The engine has 9.2 compression ratio and water cooling. The prototype was designed using commercial software for 3-D modeling “Autodesk Inventor” and made using an CNC machine. Prototype design and experimental testing have been carried out at the Faculty of Mech. Eng., University of Belgrade.

In order to simplify prototype design, the part of existing induction system is used: intake air plenum and initial part of inlet pipes. Other, newly designed part of inlet pipes has complex geometrical shape because in its initial part cross section must be circular to match the existing pipes, while at outlet cross section must be tetragonal to enable deflector rotating motion. The transition between the circular and rectangular cross-section is continual to enable good flow characteristics. Since such a complex geometry is hard to be properly realized in closed space, even using CNC machine, the assembly is made of two halves – upper and lower that are connected by screws. The connection between the pipes and new part is also realized by screws. Simpler connection would be by welding but in this case simple disassembling would not be possible and eventual corrections of geometrical shape would be very complicated. Screw connection between the pipes and new part also enable the insertion of different pipe in order to investigate the influence of pipe length.

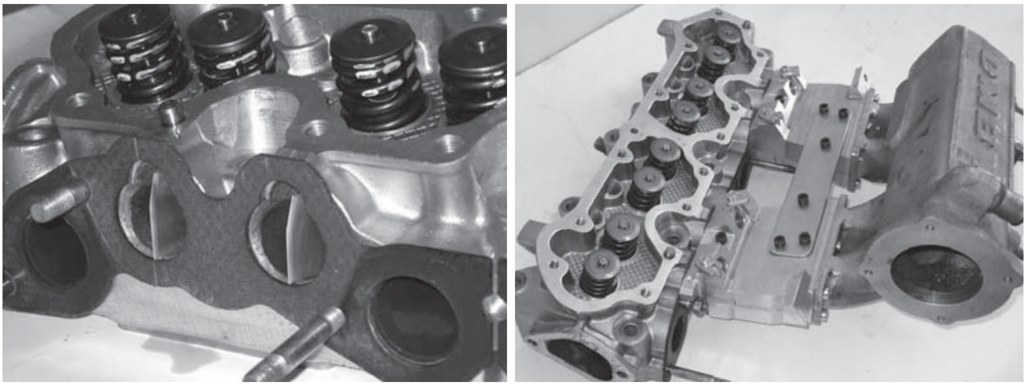
Fig. 2 and 3 show prototype of “Dual port” variable induction system. In fig. 2- deflectors are in their closed positions directing air flow into primary inlet channels in engine head and enabling flow acceleration and tangential entry into cylinder. This corresponds to engine low load. In fig. 2-b deflectors are in open positions and both parts of inlet channel are active (full engine load).



a) *b)*

Fig. 2 *Design of induction system “Dual port” with directing deflectors in a) closed position and b) open position.*

Certain modifications also had to be done in cylinder head. Fig. 3-a shows inserted tin wall plates which separate intake channel in the head. Fig. 3-b shows complete assembly of cylinder head with “Dual port” variable induction system.



a) b)

Fig. 3 *Detail of engine head with longitudinal tin plates inserted in head induction channels (a) and assembly of engine head and the prototype of variable induction system "Dual port" (b).*

In laboratory conditions the deflector positions were adjusted manually. After system experimental testing and optimal deflector position mapping, deflector actuating can be controlled by the engine Electronic Control Unit using appropriate actuator. Since only two deflector positions are required, a relative simple and cheap solution with pneumatic membrane device can be used. Membrane moving which is transmitted via lever system to the deflectors is activated by ECU using pneumatic valve and pressure from engine induction system.

3 TESTING PROCEDURE AND EXPERIMENTAL RESULTS

Fig. 4 *Detail of combustion chamber with pressure transducer location (engine 3. cylinder)*

The expected effect of increased turbulence and swirl motion (deflector closed) is the acceleration of combustion process at engine partial load, what should increase fuel economy. To study these effects, a number of engine “load characteristics” at different speeds were recorded. In addition, in-cylinder pressure in 50 consecutive cycles was recorded at each operating point. Individual cycles as well as average cycle are later analyzed and heat release and heat release rate were determined using the methods of pressure record thermodynamic analysis [3,4,5,6].

Fig. 5 shows specific effective fuel consumption (g_{e0}) and thermal efficiency (η_{eo}) vs. engine load at 2800 and 3300 rpm at the same ignition timing. All values are plotted comparatively for two deflector position – closed port (flow is directed into one half of inlet channel) and open port (full inlet channel cross section is active). Since mixture strength has significant impact on fuel economy, the air access ratio (λ) is also shown in order to separate the different influences. Comparative are only the points where air access ratio is the same and the difference in fuel economy is the consequence of the rate of combustion.

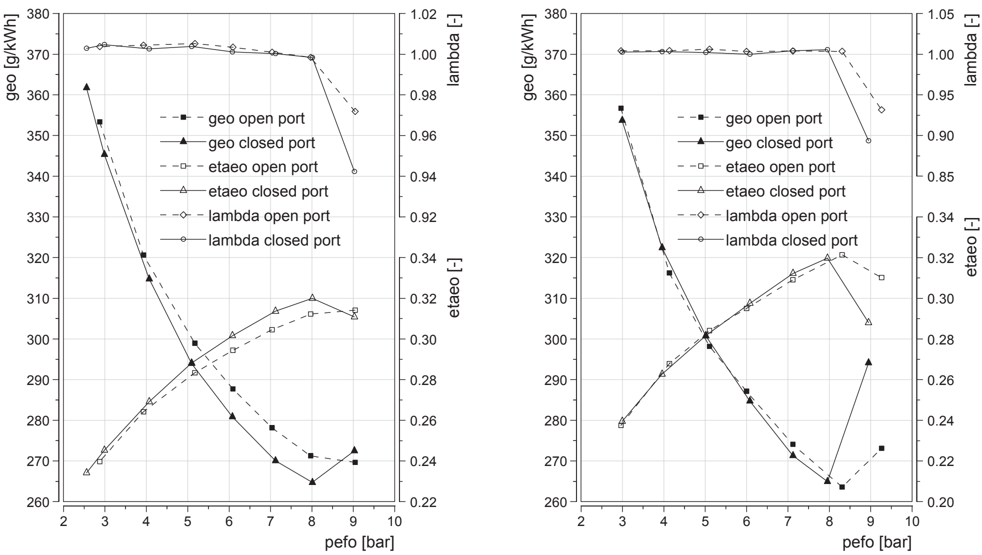


Fig. 5 *Engine characteristics vs. load at n=2800 and 3300 rpm; geo -specific fuel consumption, etaeo- effective thermal efficiency, lambda-air access ratio.*

As can be seen, specific fuel consumption is lower and thermal efficiency is greater in the condition of increased flow velocity in inlet channel (closed port), except at full engine load where mixture strength is richer and consequently fuel economy is worse. Nevertheless, the differences in fuel economy are relatively small, about couple of percent, except at *n*=2800 rpm where the differences achieve a few per cent.

Fig. 6 shows the universal diagram of specific fuel consumption relative difference recorded in engine whole operating range. This relative difference is defined as (g_{eclose}-g_{eopen})/g_{eopen}, so that negative difference means that the consumption is lower in the case of increased flow velocity (closed port). Positive difference (lower consumption with open port condition) is mainly the consequence of the difference in mixture strength.

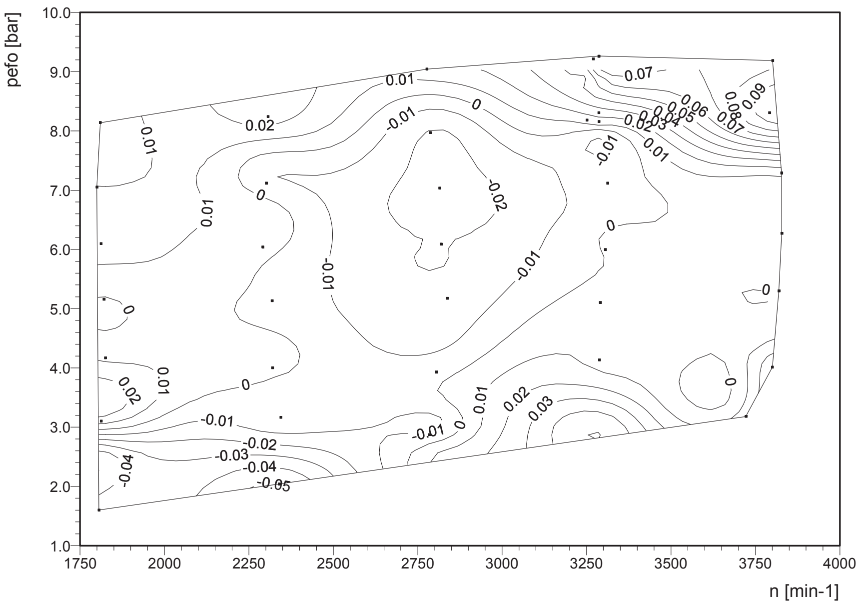


Fig. 6 *Universal diagram of specific fuel consumption relative difference*

The typical results of cylinder pressure recording and thermodynamic analysis for a working regime, where the effects of "dual port" are the most expressed and an improvement of engine performances is the biggest, are shown at figures 7. At other engine working points, these effects are smaller. Besides indicated cylinder pressure *p*, figure 7 show normalized integral heat release *X* (ratio of released heat vs. total heat corresponding to the mass of fuel per cycle) and the rate of heat release $dX/d\alpha$ (heat released per crank angle). It can be seen that peak pressure is 10% higher in the case of closed port, as well as heat release rate is higher (~ 20%) and combustion duration is shorter (~ 25%).

At every engine operating point a series of 50 consecutive cycles were recorded in order to analyze cycle variations of working process. Thus, thermodynamic analysis was carried out on single recorded cycles (diagrams "c" and "d") and on average cycle (diagram "f").

For analyzing the speed and stability of the combustion process the following parameters has been considered:

- Variations of cycle maximum pressure p_{max};
- Variations of combustion process defined as angular duration of combustion 10-95% of burnt fuel mass (X=0.1-0.95)
- Comparison of heat release X and rate of heat release $dX/d\alpha$ obtained by average cycle analyzing.

As can be seen, combustion process is faster in the case of increased air velocity in inlet channel (closed port) what indicate heat release and the rate of heat release of average cycle. Besides, the cyclic variations of combustion are considerably lower what can be concluded from both cycle maximum pressure variations and heat release cycle variations.

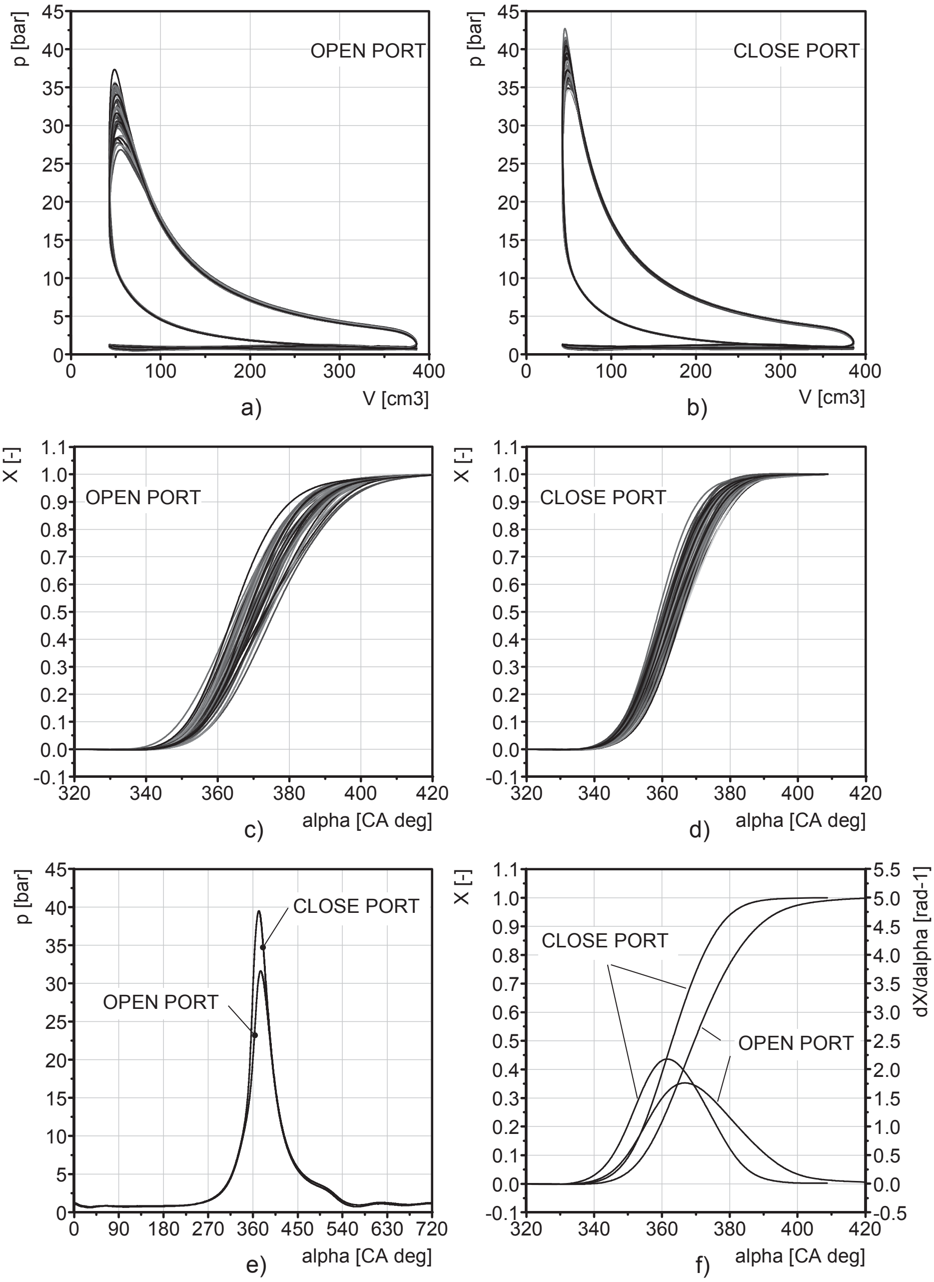


Fig. 8 *Cylinder pressure (a,b) and heat release X (c,d) for 50 consecutive cycles; cylinder pressure (e) and heat release X and heat release rate dX/dalfa (f) for average cycle, in function of crank angle (alfa). Engine load* p_e*=6.2 bar and speed n=2300 rpm.*

Figure 8 shows the universal diagram of the difference of angular combustion duration variations for the case of "closed port" and "open port" condition. Lower cyclic variation of combustion results in lower variation range of combustion angular duration, what means higher combustion process stability. Therefore negative difference of variation range on the diagram means lower variation in the case of increased air velocity in inlet channel (closed port). As can be seen negative difference is evident in all engine load and speed and ranges from a few crank angle degrees to even -10 crank angle degrees. As a result of increase intake port velocity and generated swirl with closed secondary port, a higher stability of combustion process leads to lower cycle variation of maximum pressure and mean effective pressure .

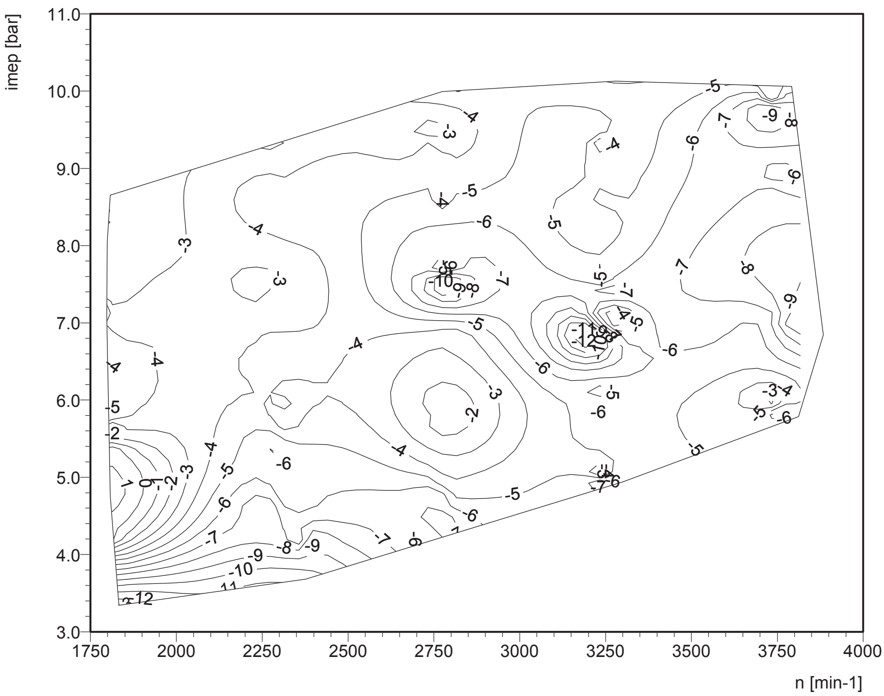


Fig. 9 *Universal diagram of the difference of angular combustion duration variation range.*

4. CONCLUSIONS

Based on the comparison of fuel consumption and thermal efficiency, as well as on combustion analyses, the following conclusions can be formulated:

- The acceleration of air flow in inlet channel by the reduction of flow area using designed "Dual port" variable induction system evidently accelerate combustion process at all engine loads and speeds. Besides, the cyclic variations of combustion process duration are significantly lower what results in lower cyclic variations in maximum pressure and mean indicating pressure. All this shows that the stability of engine working process is increased.

- Combustion acceleration and stability enable increased fuel economy of the engine at low engine loads and speeds where engine volumetric efficiency has not been decreased by increased intake air velocity. Nevertheless, measured fuel consumption reduction is at the level of couple per cent, lower than expected.
- Further investigation and optimization of variable induction system is required in order to consider the possibilities of better utilization of increased rate of combustion. There is the indication that the optimization and adaptation of some control parameters (for example ignition timing) would enable better effect of faster combustion on engine fuel economy.

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